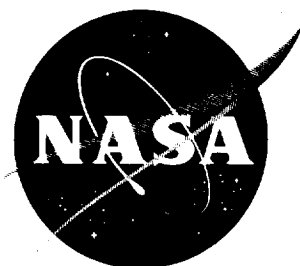


NO. 710-6

NASA TN D-1062

NASA TN D-1062



TECHNICAL NOTE

D-1062

A DIGITAL SOLAR ASPECT SENSOR

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WASHINGTON

September 1961

A DIGITAL SOLAR ASPECT SENSOR

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SUMMARY

The solar aspect sensor described herein performs the analog-to-digital conversion of data optically. To accomplish this, it uses a binary "Gray code" light mask to produce a digital indication, in vehicle-fixed coordinates, of the elevation and azimuth angles of incident light from the sun. This digital solar aspect sensor system, in Explorer X, provided measurements of both elevation and azimuth angles to ± 2 degrees at a distance of over 140,000 statute miles.

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INTRODUCTION

In modern space technology it often is desirable to convert scientific data gathered by a space vehicle into digital form before transmission to the ground. Digital data are free from the errors caused by non-linearity and drift during amplification and transmission. Moreover, most automatic data handling and processing techniques require the presentation of data in digital form. However, analog-to-digital conversion is often an undesirably complex operation when done electronically, especially when it must be performed in a space vehicle. The digital solar aspect sensor performs analog-to-digital conversion optically. It uses a binary "Gray code"* light mask to produce a digital indication, in vehicle-fixed coordinates, of the elevation and azimuth angles of incident light from the sun.

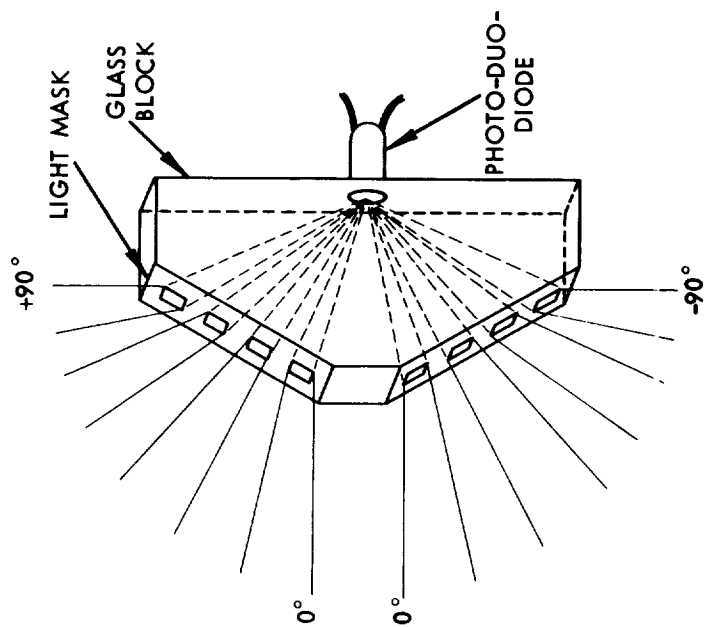
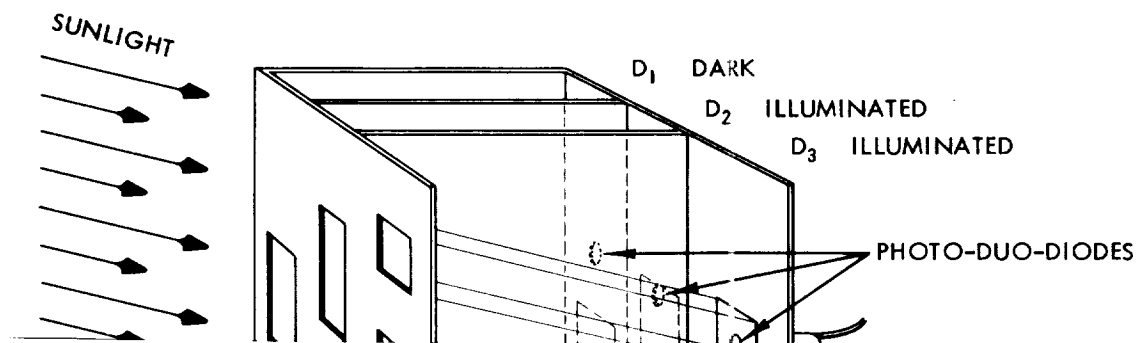
The digital solar aspect sensor has features which make it more desirable in many applications than other types of solar aspect sensors. It is not subject to errors introduced by earth shine; it has no components which can drift; and it requires no in-flight calibration. The digital sensor is low in weight, and simple in construction, and requires only the amount of power needed to drive the output load. The field of view can be made to include any desired solid angle, and areas of fine and course resolution can be produced by means of non-uniform quantization of the field of view.

PRINCIPLE OF OPERATION

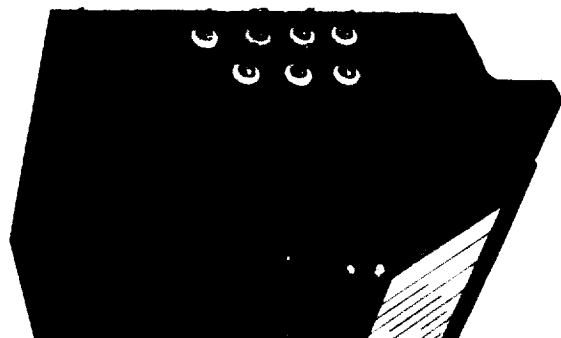
The digital solar aspect sensor consists of a number of photo-duo-diodes placed behind a light mask with slit openings as shown in Figure 1. Opaque separators are situated

*Gray, F., "Pulse Code Communications" U. S. Patent Number 2,632,058, March 17, 1953

parts. The elevation angle of the sun, in satellite coordinates, is indicated by the six bit binary number which appears at the output terminals each time the sun appears in the fan. The time of the appearance of the sun in the fan provides a measure of the azimuth angle of the sun as a function of time. This sensor weighs nine ounces and is less than three inches in diameter. The photo-duo-diodes operate as nearly perfect switches into a 50,000 ohm load.



(b) Binary light sensor with a 180° fan field of view



Digital solar aspect sensor

Figure 2 - Digital solar aspect sensor with a 180-degree fan field of view quantized into 63 parts

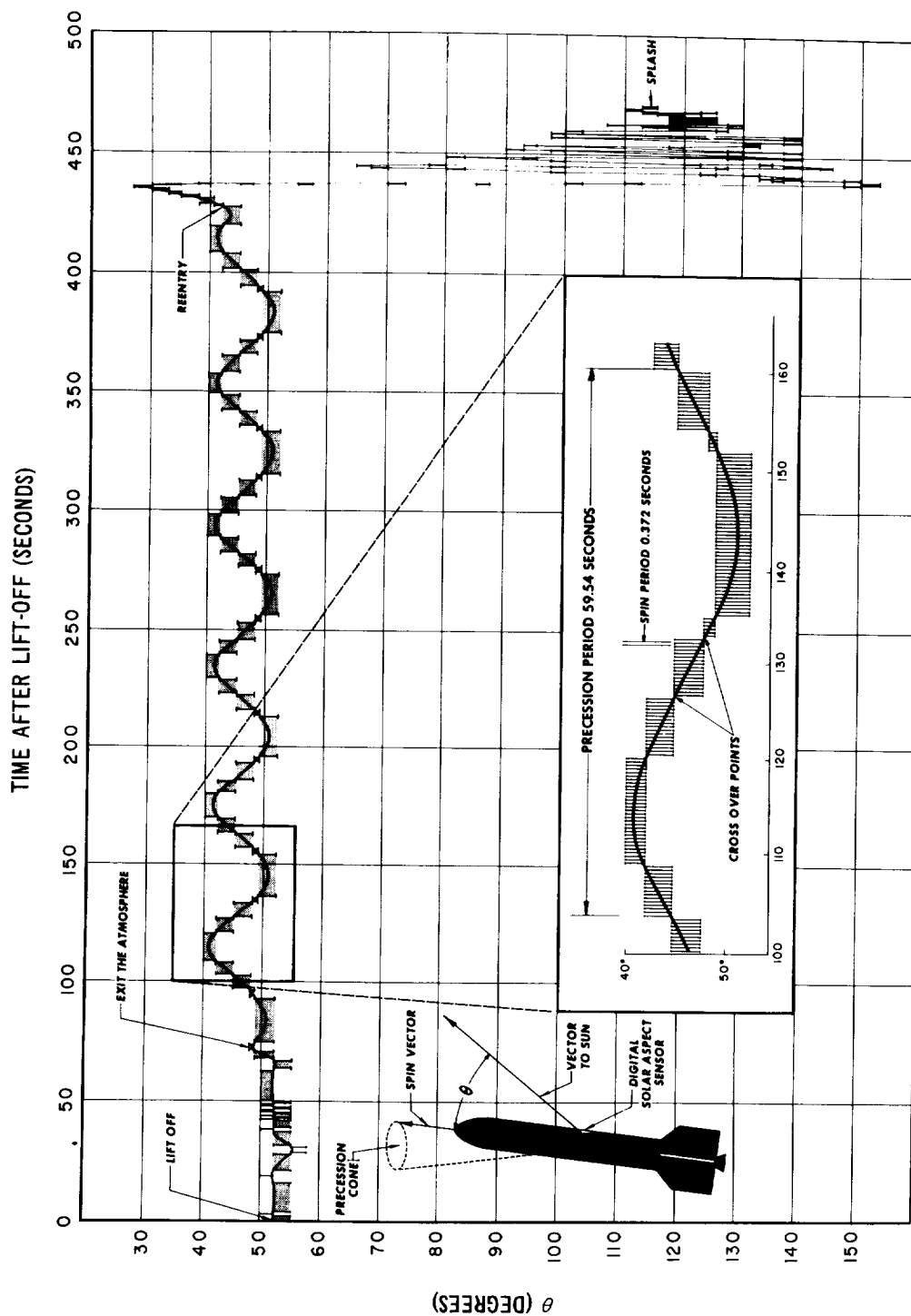


Figure 3 - Angle between rocket spin axis and sun vector as a function of time (Aerobee-Hi Rocket fired from Wallops Island, Virginia, in November 1960)

corresponded to one of the 63 quantization windows. This number indicated that the angle θ between the spin axis and the sun vector was within the confines of one of the grey areas on the graph at the time indicated. The irregularities in this angle early in the flight are due to wind effects in the atmosphere. Because of the swift passage of the rocket from the region where the tail fins are effective into essentially outer space conditions, an abrupt change in the character of the fluctuations occurs at about 75 seconds. During the major portion of the flight the smooth sine wave variation of the angle θ results from the force-free precession of the spinning rocket, which arises because the principle moments of inertia were not aligned with the rocket spin axis. The large fluctuations occurring after 425 seconds of flight result from the rocket's striking the atmosphere tail-first, turning over, and falling the remaining distance nose-down, oscillating like a falling arrow.

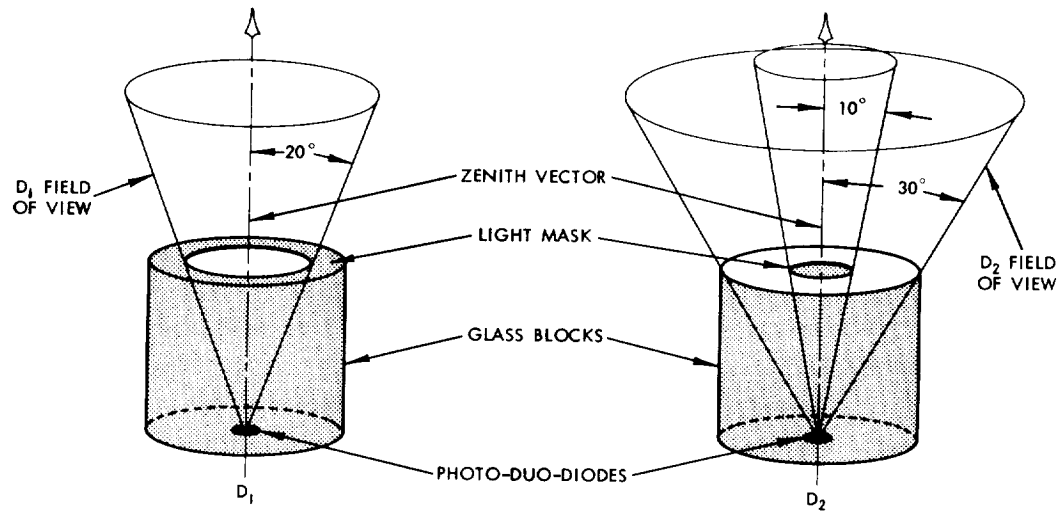
Note that under the conditions of force-free precession the sun vector can be measured much more precisely than the nominal 2.5 degree quantization window width would otherwise permit. This is accomplished by the simple expedient of drawing a smooth curve through the crossover points as the angle θ shifts from one window to the next. Owing to mechanical irregularities in the photosensitive semiconductor wafers, the quantization windows are not uniform, as can be seen in the figure. However, the crossover points are quite sharp and can be calibrated to better than ± 0.2 degrees.

STABILIZED SATELLITE ASPECT SENSOR

A second kind of digital solar aspect sensor with a wide angle field of view is illustrated in Figure 4. This type of solar aspect sensor can be used on either a spinning or a non-spinning satellite. Its wide angle characteristics make it useful for solar acquisition and coarse alignment of stabilized vehicles. Its spherical coordinate system makes possible the use of only the elevation or only the azimuth sensors for special applications, such as measuring the incident angle of radiation on solar cells.

The two bit elevation sensor shown in Figure 4a has a 30 degree half-angle conical field of view. Upon the sun's appearance within this 30 degree cone, either one or both of the photo-diodes D_1 and D_2 will be illuminated. The particular combination of off-on conditions will indicate whether the sun is within 10 degrees of the sensor axis, between 10 and 20 degrees, or between 20 and 30 degrees. With the sun's elevation with respect to the sensor axis known, the azimuth angle about this axis is then determined by means of two additional sensors having the fields of view shown in Figure 4b. Here, it will be noted that the elevation sensor uses a Gray code mapped into concentric circles, and the azimuth sensor uses a Gray code mapped into a radial pattern. Thus, the principle of only one decision per transition between quantization windows is preserved.

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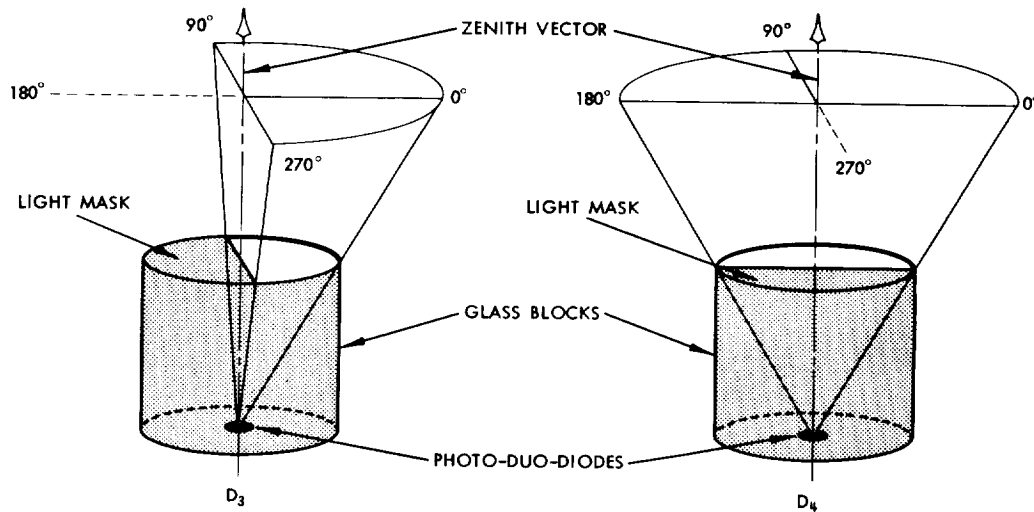
(a) 2 bit elevation sensor

If sun is within 10° of zenith $D_1 = 1, D_2 = 0$

If sun is between 10° and 20° of zenith $D_1 = 1, D_2 = 1$

If sun is between 20° and 30° of zenith $D_1 = 0, D_2 = 1$

If sun is more than 30° from zenith $D_1 = 0, D_2 = 0$



(b) 2 bit azimuth sensor

If sun is in first quadrant $D_3 = 1, D_4 = 1$

If sun is in second quadrant $D_3 = 0, D_4 = 1$

If sun is in third quadrant $D_3 = 0, D_4 = 0$

If sun is in fourth quadrant $D_3 = 1, D_4 = 0$

Figure 4 – A solid angle Digital Solar Aspect Sensor provides a digital indication of the elevation and azimuth angles of the sun in a sensor fixed coordinate system

The sensor in Figure 5 has a four bit elevation detector consisting of the four circular masks in the center row of the sensor. In addition, it has a six bit azimuth detector shown by the two rows of three radially cut masks. The ten detectors constitute an elevation and azimuth sensor with a 60 degree half-angle conical field of view. The various rectangular masks on the side and end of the sensor have fan fields of view 90 degrees long and 30 degrees high. These fans are quantized both horizontally and vertically, and are so aligned that the quantization windows of each fan merge with those of the 60 degree half-angle cone and also with those of the other fans. Thus, the sensor has a 180 degree solid-angle field of view, and it can measure both the elevation and azimuth angles of incident light from the sun over an entire hemisphere to better than ± 3 degrees. Two such sensors mounted diametrically opposite each other on a space vehicle can view the entire sky; Their combined output is an eleven bit binary word uniquely defining the position of the sun at all times within a solid angle segment less than six degrees on a side. The word could be sampled at any desired rate. Accurate calibration of the position of the crossover lines from one window to the next can be used to increase the accuracy to within ± 0.2 degrees, provided there is rotation of the vehicle relative to the sun vector.

USE ON EXPLORER X

The digital solar aspect system has demonstrated its ability to provide accurate data under extremely difficult conditions. The Explorer X satellite was equipped with a digital solar aspect sensor which provided ± 2 degree measurements in both elevation and azimuth angles at a distance in excess of 140,000 statute miles. Severe fading and data dropouts created by nulls in the spinning antenna pattern caused no degeneration in solar aspect accuracy. A complete description of this system and the resulting data is in preparation and will be published in the near future.

FUTURE APPLICATIONS

Advanced digital aspect systems suitable for completely automatic data processing techniques are now under development at the Goddard Space Flight Center. These systems will be capable of operating with the sun in the daytime and the moon at night. They will also incorporate standard infra-red earth horizon detectors for either day or night operation. A complete description of these systems is also in preparation.

Many of the satellite and space probe experiments to be flown in the coming months will require optical aspect information. In many cases, systems using the digital type aspect sensor can provide the most satisfactory results with the greatest system reliability.

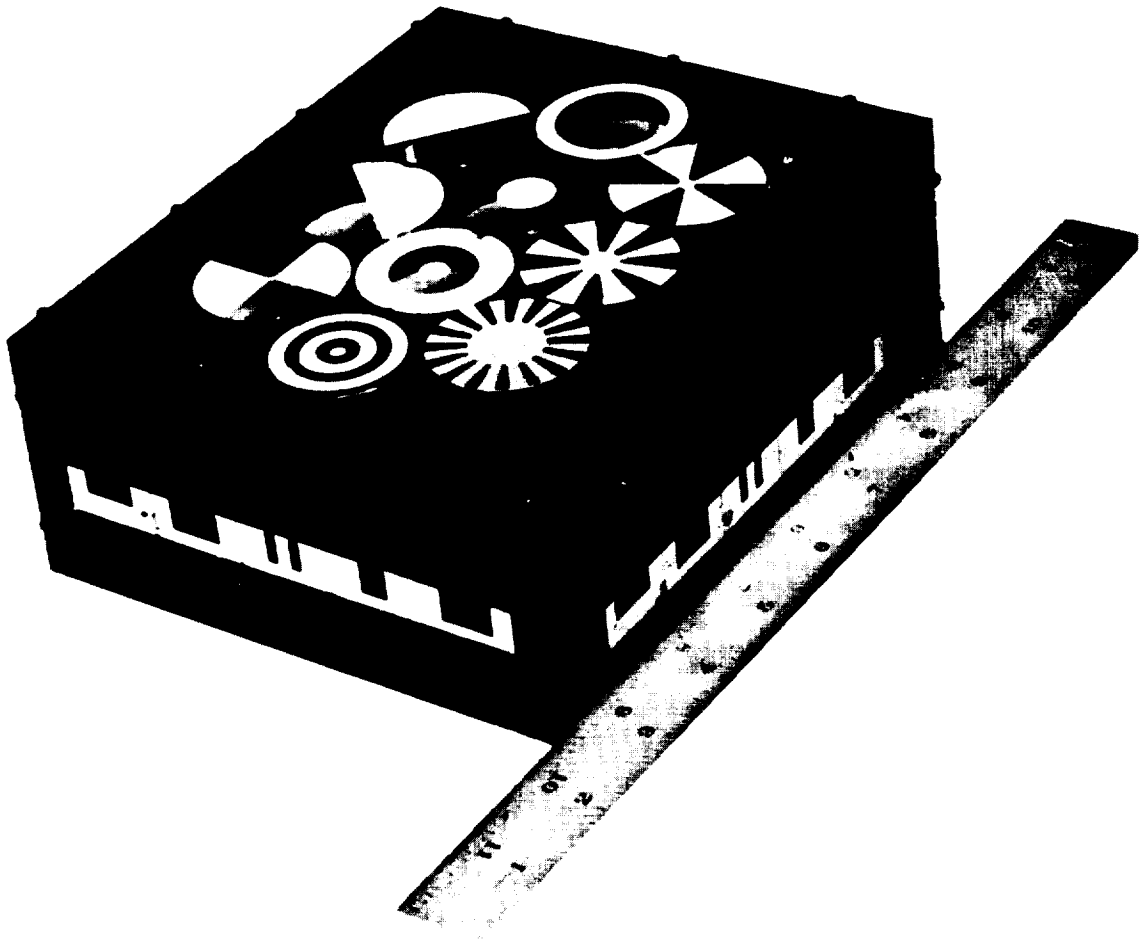


Figure 5 – A Digital Solar Aspect Sensor with a 180 degree solid-angle field of view

ACKNOWLEDGMENTS

The author expresses his appreciation to Mr. David Schaefer, of the Goddard Space Flight Center, for his many valuable suggestions and to Mr. Robert M. Porter of Goddard Space Flight Center for his assistance in fabrication and testing.

